An Intelligent Standby Power Control System Design based on User Location and Appliance Usage Pattern in Smart Home

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Abstract

The standby power controlling system that is currently used works by automatically blocking standby power upon sensing the use of electricity or by the user's manual on/off controlling. As this type of system, however, requires the voluntary participation of the user for resupply of electric power, it causes inconvenience to the user and necessarily involves the user's intervention for power saving, which is the significant disadvantage of this system. In consideration of user convenience as well as standby power saving, this study suggests a system that automatically blocks and resupplies standby power depending on the user's utilization pattern and movement within an appliance's sensing zone. The system is a ZigBee structure based on IEEE 802.15.4, a low electric power wireless network, and two narrow angle–type PIR sensors are installed at the entrance and given an ID each so that they can recognize the entrance and exit of users in the order of ID sensing. In addition, one ultrasonic sensor is installed for sensing the user's key, thus recognizing the user. To verify the standby power saving effects of the suggested system, scenarios were made for each user's pattern, and the quantity of standby power saving was comparatively analyzed.

Keywords*: Standby Power, Energy Saving, ZigBee, User Location, Context Awareness*

1. Introduction

Throughout the world, energy prices are increasing as energy resources are declining. Climate change has become a global issue as greenhouse gas emissions increase. Accordingly, countries are actively promoting energy efficiency policies to reduce energy consumption [1]. Korea, for example, is the 9th highest energy consuming country in the world in 2011, and it has been reported that the increase rate of carbon emission in this country was the highest in the year [2]. NIA(National Information Society Agency) of Korea estimates that domestic CO2 emission increases about 2.2% on average every year, and that in 2012, the amount will reach 688 million tons. The CO2 emission in the IT sector is expected to account for 3.1% of the entire emission, which is far higher than the global average emission of 2.0%. This present state results from rapid changes in demands for electric power and in product market conditions, including the emergence of products that consume a lot of energy in the application of IT. This trend is expected to continue in the future as electronic products, as well as IT, become more advanced. As the number of office devices, such as copy machine, fax machine, computer, and printer, as well as "always-on" devices like home network and set-top boxes that work 24 hours a day, increases, the issue of energy efficiency among electric appliances in line with the advancement of energy saving technology is highlighted, not only due to the electricity consumption generated in the use of these devices, but also due to the power consumption they engender during standby mode [3-7].

IEA(International Energy Agency) estimates that in OECD's 34 member countries, each household consumes standby power as high as 60W, which is about 10% of its total power consumption. In the case of the U.S., the standby power consumption is 5% of the entire electric power consumption, which is relatively small, but this amounts to about 1.3 billion dollars every year, which indicates that the issue of standby power consumption should not be overlooked anymore [8]. According to KERI (Korea Electrotechnology Research Institute), in Korea in the year 2011, standby power as much as 209kWh per household was consumed during the year, which accounts for 6.1% of the total electric power consumption (3400kWh) of one household during the year. According to one research, if appliances not used were plugged off, electric energy as much as 17.4kWh could be saved every month

[9]. In addition, it is estimated that each household in Korea owns 23.9 units of home appliances. As the types of appliances become diversified, the number of devices owned in each household is increasing as much as 1.5 every year, and the number of network devices is increasing as well. Thus, it is expected that during the following 20 years, the standby power consumption will increase about 5.8% every year [9]. If things continue at this pace, the standby power consumption by 2020 will account for about 25% of the entire household power consumption [3]. However, most home appliance users are not aware of the necessity of saving electric power and resources by minimizing standby power consumption; thus, a system to technically reduce the consumption must be developed.

In 2004, the Korean government issued a proclamation that it would introduce "Standby Korea 2010" to manage the standby power of all electronic appliances under 1W. In this effort to develop standby power saving technology, it will provide purchasing, distributing, and promoting support for the technology [10][11]. Accordingly, the standard of standby power measuring 1W or less was applied to 30 kinds of electronic products released up to 2010. As a result, 170kWh for each household and 2,550GWh nationwide were saved. By 2020, it is estimated that 2,800kWh for each household and 42,000GWh nationwide will have been saved [12][13]. Despite such efforts, however, a number of electronic products with more than 1W standby power still require manual control for standby power blocking and supply, which indicates the necessity for the consumer's active participation for standby power saving.

Thus, this study intends to design a system to intelligently and automatically control the on/off modes standby power by grasping the location and usage patterns of users within a zone as well as reducing standby power consumption that is wasted with the user not noticing it. The suggested system recognizes users to control or prevent the consumption of standby power of appliances that are not often used by the users with the power supplied for all devices in the zone as the system senses their presence. Afterwards the system supplies electric power only to devices that the user in its presence would consistently use. The data containing the user's entrance and exit are acquired by means of the two PIR sensors at the entrance of each zone, and the data for user recognition are obtained through key sensing from the ultrasonic sensor at the entrance of each zone. Furthermore, the system changes the frequency of use of each device once it senses any change in the list of major appliances used, which is reflected as it decides to block or supply standby power to certain devices upon the user's entrance.

This study consists of the following sections: Chapter 2 presents existing studies on standby power; Chapter 3 states the intelligent standby power control system suggested in this study; Chapter 4 evaluates it by comparing the system with existing standby power devices based on the scenarios; Chapter 5 presents the conclusion and issues for future study.

2. Related work

Standby power is the electricity consumed by appliances while switched off or not performing their primary functions [14]. In other words, standby power means the electric power consumed while the devices are plugged in and with the major functions in an idle state as in Figure 1.

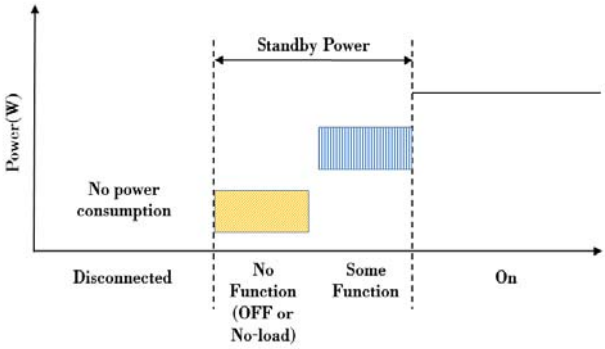

Figure 1. Standby power

IEC (International Electrotechnical Commission), IEA, the U.S., Japan, Australia, etc. have their definitions of standby power, and there has been no unified, international terminology in this regard. The IEC defines standby power is the lowest level of electricity consumed by appliances, which cannot be switched off (influenced) by the user, and may persist for an indefinite time when an appliance is connected the main electricity supply [15]. The Korea Energy Management Corporation defines standby power as "power consumed while the device is connected to the power source and waiting for ON signals from outside with the major functions in an idle state, including the consumption upon power-off and during the warming up and booting of the device" [16].

It is difficult to apply a definition of standby power in all machines since the running and operating patterns of appliances and office devices are different. Thus, the term may be classified into no-load, off mode, passive standby, active standby, and sleep mode depending on whether the running totally stops or remains minimized with the plug on as in Table 1. Power consumption with no operation at all is called the off mode standby power, the consumption when the power is turned off by means of a remote controller passive standby, the consumption when the power of a networked digital appliance is turned off active standby, and the consumption in a standby state for normal operation of the device sleep mode standby power [15][16]. Appliances distributed before mostly had only off mode, passive standby, and sleep mode, but as network devices have become common recently, standby power consumption at active standby mode has been increasing. Introduced with the emergence of the set-top box system, active standby indicates a state that consumes a lot of standby power, with the internal circuit operating in order to wait for wire/wireless communication signals from outside even if the consumer has turned the system off. It has been estimated that standby power consumption could measure as much as 3-4W on average, and 10W at most [17]. If just one set-top box system silently consumes 20-40W on standby power, taking measures on this becomes of great urgency.

Table 1. Types of standby power

Category	Description	Power Status	Products
No Load	Power consumed with the plug on	Switched off	External Power Supply, electric rice cooker
Off	Power consumed even with the power turned off through the power on/off button; about 0-3W	Switched off	TV, VCR, audio, DVD player, microwave, PC, monitor, printer, copier
Passive Standby	Power consumed with power turned off through a remote controller	Switched off	TV, VCR, audio, DVD player, air cleaner, air conditioner
Active Standby	As for digital devices connected to a network, standby power as much as 20-40W is consumed for communication with the power on even if it is switched off	Switched off	Set top box, home network system
Sleep	Power consumed in a standby state that would not be used while the device is working	On and standby	PC, monitor, printer, facsimile, copier, scanner, multifunction device

Every product with a power on/off switch consumes a measure of standby power, especially electronic products such as consumer electronics, office equipment, and white goods whose standby time is a lot longer than their operating time, thereby consuming a large amount of standby power. Figure 2 shows the minimum, average, and maximum standby power measured from each electronic product, as well as the number of products measured at Lawrence Berkeley National Laboratory. It indicates that office devices and digital appliances connected to a network consume a particularly high level of standby power [17].

The best way to block standby power is to plug it off completely. Standby power-saving devices developed so far focus on user convenience by such means as remote controller or timer that blocks power supply automatically after a certain time period. Some methods induce users to check power consumption and control power supply for themselves. Most of the methods above, however, require the voluntary participation of the device users, and even auto plug-off methods require the user's manual intervention for resupply of power, which causes inconvenience. In the case of active standby, especially, standby power consumption continues for at least 20 hours a day; thus, it is necessary to

develop a device and system that can automatically block and resupply power without the user's intervention.

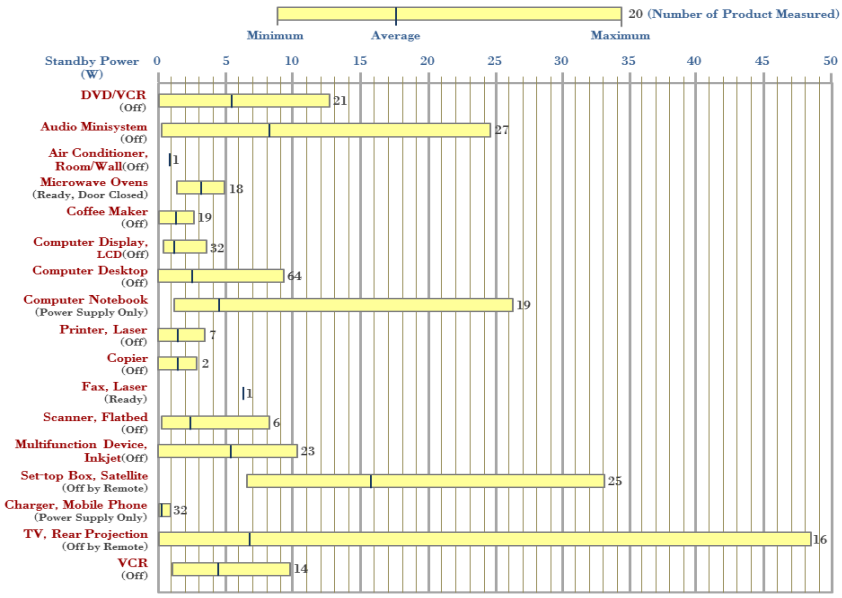
20 (Number of Product Measured)
Minimum
Average
Maximum
Standby Power (W)
0 5 10 15 20 25 30 35 40 45 50
DVD/VCR (Off) 21
Audio Minisystem (Off) 27
Air Conditioner, Room/Wall(Off) 1
Microwave Ovens (Ready, Door Closed) 18
Coffee Maker (Off) 19
Computer Display, LCD(Off) 32
Computer Desktop (Off) 64
Computer Notebook (Power Supply Only) 19
Printer, Laser (Off) 7
Copier (Off) 2
Fax, Laser (Ready) 1
Scanner, Flatbed (Off) 6
Multifunction Device, Inkjet(Off) 23
Set-top Box, Satellite (Off by Remote) 25
Charger, Mobile Phone (Power Supply Only) 32
TV, Rear Projection (Off by Remote) 16
VCR (Off) 14

Figure 2. Standby power of products

3. Intelligent standby power control system

The intelligent standby power control system suggested in this study is designed based on the IEEE 802.15.4 ZigBee technology which is one of the most common low-power consumption communication technologies in the market [18-20]. As shown in Figure 3, it includes two PIR sensors to recognize entrance and exit in several locations and an ultrasonic sensor to identify the persons. At each section, some appliances subject to standby power controlling are arranged, and their standby power is controlled by the processor of the suggested Intelligent Standby Power Control System depending on the condition.

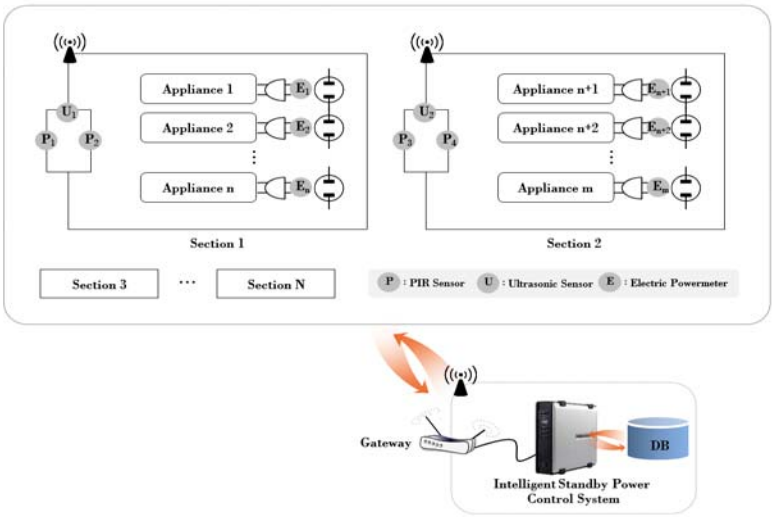

Figure 3. Structure of intelligent standby power control system

3.1. Standby power saving devices

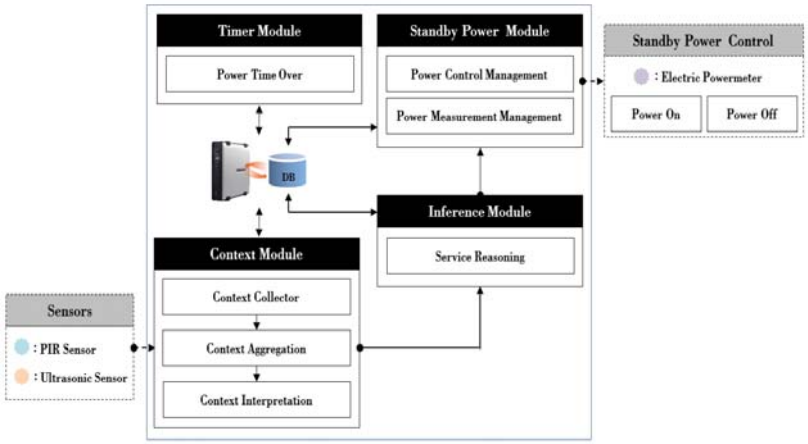

Figure 4. System design

3.1.1. Context module

Figure 4 shows the flow chart of the standby power control system developed in this study. The system's context collector collects raw data from the PIR sensors and the ultrasonic sensor recognizes the users and their locations at certain intervals. The collected raw data is processed by the context aggregation processor, interpreted for information on the system condition, and saved so that the context interpretation processor can recognize the situation. The raw data received from the PIR sensors is compared with the sensor ID information stored in the database in order to recognize the entrance, exit, and location of the user. The raw data received from the ultrasonic sensor is compared with the user information to recognize certain users.

3.1.2. Inference module

The Inference Module infers the users' appliances enlisted in the database based on the user location and recognition information stored in the context module. When the user uses appliances other than those in the list stored in the database, the history of using appliances in the database is updated, and the list of appliances whose use frequency is reduced is changed accordingly. Afterwards, the service reasoning processor infers the user's appliances from the database of the history of appliance uses. If more than one user is recognized in the same zone, the system counts the number of users and supplies power to all appliances for them.

3.1.3. Standby power module

Once the users and their movements are recognized, the Power Control Management checks the IDs of the appliances in a zone, grasps the list of appliances for certain users from the database, and sends signals of power-on or power-off to the actuator of the electric Powermeter. Supplied with power, the Powermeter sends the data on power consumption through the gateway by means of Power Measurement Management. If the user wants to use an appliance not registered in the database, power is supplied by manual controlling of the Powermeter in the system, and the system saves the use history of the appliance and time of use in the database.

3.1.4. Timer module

If the user who is working in the zone leaves the area with a certain appliance on and does not come back for a period of time, the Power Time Over processor blocks the power supply automatically, which saves standby power and thus reduces the general waste of electric power.

3.2. Transmission and reception of data

3.2.1. Checking of a Certain User's Entrance and Exit

To grasp a user's entrance or exit into a zone and count the number of people present, the suggested system adopts PIR sensors. PIR sensors recognize the infrared light from human bodies and movements in a zone to grasp a user's presence. These PIR sensors, however, may not recognize any presence if the user is located at a blinded area in the zone or the movement is too insignificant to be sensed. Multiple sensors may be necessary depending on the size of the zone, and the number of users in presence may not be recognized. Hence, the system suggested in this study uses the two PIR sensors with an ID each at the entrance to count the number of users in the zone and check their entrance or exit as in Figure 5(b). The system recognizes a user by means of the first PIR sensor in the order of IDs saved in the PIR sensor, and then the entrance is recognized when the second PIR sensor recognizes the user. Likewise, when the second PIR sensor recognizes movement and the user's movement is sensed by the first PIR sensor, an exit is recognized. The system's PIR sensor transforms the infrared light in the 95°×90° range into a voltage for sensing as shown in Figure 5(a). However, when the two PIR sensors installed in the entrance of the zone maintain an existing wide angle as in Figure 5(a), it frequently occurs that at the intersection of the two sensors, exit is mistakenly recognized right after one's entrance. The system, therefore, changed the sensing angle of the PIR sensors to a narrow angle as in Figure 5(b) to correctly recognize entrance and exit.

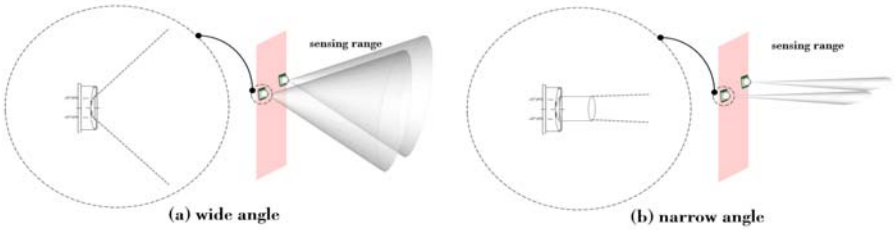

Figure 5. Changes in the Sensing Angle of the PIR Sensors to Recognize One's Presence Correctly

Table 2. Receiving packet information of PIR sensor

Packet	Length	No	Description
Header	10 bytes	0 / 1 / 2 / 3-4 5-6 / 7 / 8 /9	STX(0x7E) / Receiving(0x45) / 0x00 / Dest Src / Length / Group ID / Type
Sensor Type	2 bytes	10-11	0x0065
Serial ID	6 bytes	12-17	
Node ID	2 bytes	18-19	
Count	2 bytes	20-21	
Battery	2 bytes	22-23	
Sensor Data	6 bytes	24-25 / 26-29	Sensing(Off : 0x0000, On : 0x0001) / Dummy
Footer	3 bytes	30-31 / 32	CRC / ETX(0x7E)

The packet of each PIR sensor transmitted to the gateway is 33 bytes in total as shown in Table 2. Presence is sensed based on the received values of numbers 24 to 25. If more than one user enters the same zone, the signals of entrance are delivered from the PIR sensors twice, and then the system increases the number of recognized users at every signal reception and saves it in the database.

3.2.2. Receiving User-recognition Data

The suggested system adopts an ultrasonic sensor to recognize users. The sensor is installed at the top of the entrance as in Figure 6, and the result is delivered except on the area covering the ground up to the upper end of the user's height. Table 3 shows the data packet structure of the ultrasonic sensor in a table. The key information is received from packets 24 and 25 of the sensor data, and the received values are compared with those in the user-recognition table stored in the database to recognize certain users.

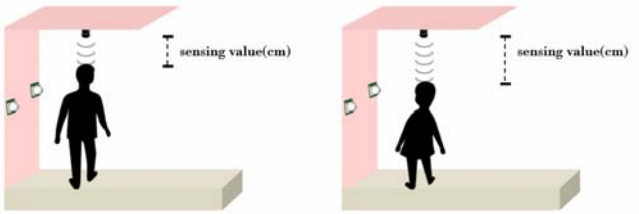

Figure 6. Ultrasonic sensor to recognize certain users

Table 3. Receiving packet information of ultrasonic sensor

Packet	Length	No.	Description
Header	10 bytes	0 / 1 / 2 / 3-4	STX (0x7E) / Receiving (0x45) / 0x00 / Dest
		5-6 / 7 / 8 / 9	Src / Length / Group ID / Type
Sensor Type	2 bytes	10-11	0x0069
Serial ID	6 bytes	12-17	
Node ID	2 bytes	18-19	
Count	2 bytes	20-21	
Battery	2 bytes	22-23	
Sensor Data	6 bytes	24-25 / 26-29	Height / Dummy
Footer	3 bytes	30-31 / 32	CRC / ETX (0x7E)

3.2.3. Data Transmission and Reception of the Powermeter

Installed to grasp the power consumption of appliances and control standby power, the Powermeter is a power consumption measuring module designed to collect data on power consumption through a gateway by means of a power consumption measuring chip. Table 4 shows the packet information received from the Powermeter. The values of current, active power, apparent power, and peak are obtained from numbers 24 to 35 of the sensor data.

Table 4. Receiving packet information of electric powermeter

Packet	Length	No.	Description
Header	10 bytes	0 / 1 / 2 / 3-4	STX (0x7E) / Receiving (0x45) / 0x00 / Dest
		5-6 / 7 / 8 / 9	Src / Length / Group ID / Type
Sensor Type	2 bytes	10-11	0x006D
Serial ID	6 bytes	12-17	
Node ID	2 bytes	18-19	
Count	2 bytes	20-21	
Battery	2 bytes	22-23	
Sensor Data	12 bytes	24-26	Current
		27-29	RawEnergy for Active Power (W)
		30-32	RawVAEnergy for Apparent Power (VA)
		33-35	Peak
Footer	3 bytes	36-37 / 38	CRC / ETX (0x7E)

Table 5. Sending packet information of electric powermeter

Packet	Length	No.	Description
Header	11 bytes	0 / 1 / 2 / 3	STX (0x7E) / Sending (0x44) / Sequence / 0x00
		4-5 / 6-7 / 8 / 9	Dest / Src / Length / Group ID)
		10	MSG Type (0x88)
Source ID	2 bytes	11-12	
Destination ID	2 bytes	13-14	
Sensor Type	2 bytes	15-16	
Command Type	2 bytes	17-18	LED_Toggle (0x0001), Reboot (0x0002), GPIO_Control (0x0003), Ping (0x0004), RSS (0x0005), NET_Info (0x0006)
Action	4 bytes	19-20 / 21-22	Port Number (0x0051) / Control (Off : 0x0000, On: 0x0001)
Footer	3 bytes	23-24 / 25	CRC / ETX (0x7E)

Once the recognition of users and their entrance are completed, signals triggering On/Off modes are transmitted to the actuator to supply or block power in a zone. The output values at GPIO (General Purpose Input/Output)—0x0000 and 0x0001—indicate the blockage and supply of power respectively shown in packets 21 and 22 in Table 5.

4. Simulation and evaluation

To evaluate the amount of standby power saving through the suggested system, this study simulates the four divided sections as in Figure 7 and installs at the entrance two PIR sensors and one ultrasonic sensor to recognize user identification and their entrance and exit. In each section, the electric powermeters are arranged from E1 to E20 to control the power consumption data transmission as well as standby power. Two individuals—A and B—are involved in the simulation as users. A is 165cm and B is 175cm. Thus, the range of identification values for users in the ultrasonic sensor is 39cm and 29cm respectively since the values are to be the height of the door, which is 204Cm, subtracted by each user's height. In the case of Section A, movement is recognized as entrance into Sections B, C, and D. If no presence signals are recognized in Section B, C, or D, and exit signals are recognized instead in Section A, the system regards it as exit from the entire space.

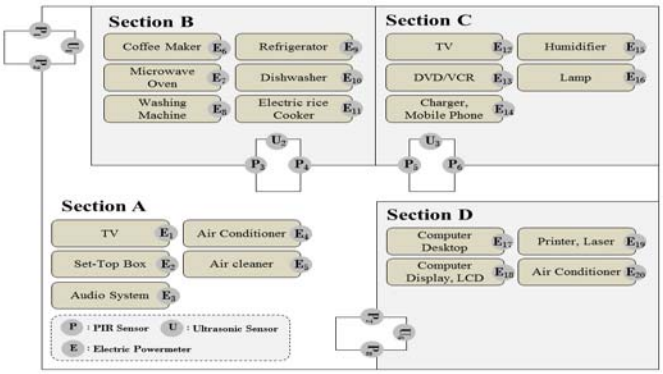

Figure 7. Environment of test bed

Table 6. Standby power of test bed

Section	Appliance	ID	Standby power	User
A	TV	1	4.33 W	A, B
	Set-Top Box	2	16.82 W(Active) 0.7W (Passive)	A, B
	Audio System	3	9.12 W	A
	Air Conditioner (Stand)	4	5.81W	B
	Air Cleaner	5	0.7W	B
B	Coffee Maker	6	1.2W	A, B
	Microwave Oven	7	3.72W	A, B
	Washing Machine	8	1.9W	B
	Refrigerator	9	Consistent power supply	A, B
	Dishwasher	10	2W	A
	Electric Rice Cooker	11	3.5W	A,B
C	TV	12	1.3 W	A
	DVD/VCR	13	12.2W	A
	Charger, Mobile Phone	14	0.86 W	B
	Humidifier	15	3.72W	B
	Lamp	16	3W	A
D	Computer Desktop	17	3.26W	B
	Computer Display, LCD	18	2.53W	B
	Printer, Laser	19	3.07W	B
	Air Conditioner (Wall)	20	1 W	A, B

Table 6 shows the IDs of appliances installed in each space, average standby power consumption, and list of users of each appliance registered in the database. The set-top box in Section A consumes active standby power as much as 16.82W even if it is switched off while connected to the network. This is recognized and managed as standby power, not firm power. The refrigerator in Section B is a device where power must be supplied to consistently regardless of a user's presence, thus standby power blockage packets are not transmitted while the power consumption data is received in the experiment.

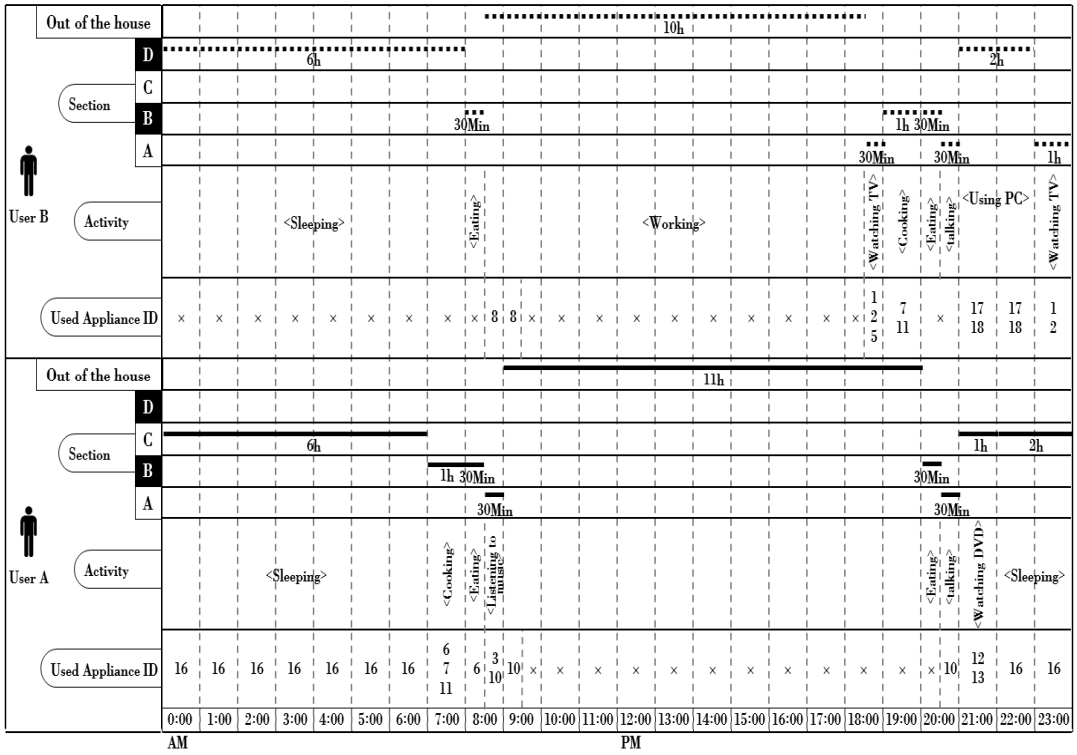

Figure 8. Scenario for experiment

Figure 8 shows the movement of users A and B and use of appliances for each time section of the 24 hours. The system supplies standby power to appliances listed in the database once it recognizes the entrance of the user. If the entrance of both A and B is recognized in the same section, the system supplies standby power to appliances in the list applied for both. If no presence is recognized in every section, the standby power and current power consumption are blocked except for items subject to consistent power supply. However, the washing machine, dishwasher, and electric rice cooker in Section B are regarded as exceptions, and their power supply is not blocked even if the user's exit is recognized from every section. If the device is turned from use mode to standby power mode, this is recognized and standby power is blocked. If user is staying in the same section for more than 1 hour, standby power of appliances that user does not use is blocked

Table 7 shows the result of analyzing the consumption of standby power during the day according to the scenario in Figure 8. System A simulates the standby power consumption in a system where there was no standby power blockage while System B simulates the standby power consumption in a system where the standby power blockage and supply were carried out for every appliance in the sections. System C shows the standby power consumption when the system suggested in this study is adopted. The standby power consumption in each case was 645.85W, 182.5W, and 120W, respectively, which indicates that the suggested system consumed the least amount of standby power. Moreover, the suggested system minimizes the manual intervention of users and intelligently controls the supply and blockage of standby power for user convenience. Thus, standby power consumption is reduced while the user does not even notice it.

Table 7. Comparison of standby power consumption

ID	Used time	System A	System B	System C
1	90 minutes	97.425W	4.33W	4.33W
2	90 minutes	15.75 W	0.7W	0.7W
3	30 minutes	214.32 W	18.24W	4.56W
4	-	139.44 W	14.525W	11.6W
5	-	16.8 W	1.75W	1.05W
6	90 minutes	27 W	2.4W	1.8W
7	90 minutes	83.7 W	7.44W	5.58W
8	60 minutes	43.7 W	4.75W	1.9W
9	24 hours	-	-	-
10	60 minutes	46 W	5W	4W
11	120 minutes	77 W	5.25W	4.67W
12	60 minutes	29.9 W	11.7W	1.3W
13	60 minutes	280.6 W	109.8W	12.2W
14	-	20.64 W	8.6W	0W
15	-	89.28 W	37.2W	0W
16	9 hours	45 W	3W	3W
17	120 minutes	71.72 W	26.08W	3.26W
18	120 minutes	55.66 W	20.24W	2.53W
19	-	73.68 W	30.7W	9.21W
20	-	24 W	10W	3W
Total Standby Power		1451.615 W	321.705W	74.69 W

5. Conclusion

As the usage of home appliances increases every year, not only does total power consumption increase, standby power consumption also rises while the devices are plugged in. Recently, appliances have been grouped in a network by such means as ubiquitous, intelligent home net, etc., leading to drastic standby power consumption changes. Devices such as the set-top box, XDSL modem, TV, PC, etc. consume standby power in the active standby mode more than before to serve the purpose of constant communication 24 hours a day. As a result, various devices and systems to save standby power have been introduced, but most of them are operated by users manually, which causes inconvenience and achieves no standby power saving without the user's voluntary intervention. Thus, this study suggests the standby power control system that blocks and supplies power automatically depending on the movement, location, and user pattern of appliances with no need for the user's manual intervention in order to reduce standby power consumption in households. In particular, this system recognizes the entrance and exit of multiple users by installing PIR sensors and an ultrasonic sensor in divided sections to control the blockage and supply of appliance standby power depending on the history of appliance use of those in presence. For intelligent controlling, the system minimizes a user's manual control of standby power and updates the users' appliance use pattern based on their history of use. In the experiment, the area was divided into several sections, and scenarios were made in a way that involved different locations and use patterns of appliances depending on two users' preferences. The case where the suggested system applies and the other case where it does not are compared to evaluate the amount of standby power saved. In future studies, standby power control system that can predict user patterns depending on human traffic and that can block power supply on unused appliances accordingly are expected to be examined.

6. Acknowledgement

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